

# Bit error rate performance on passive alignment in tree space optical links using large core fibers

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Space Administration



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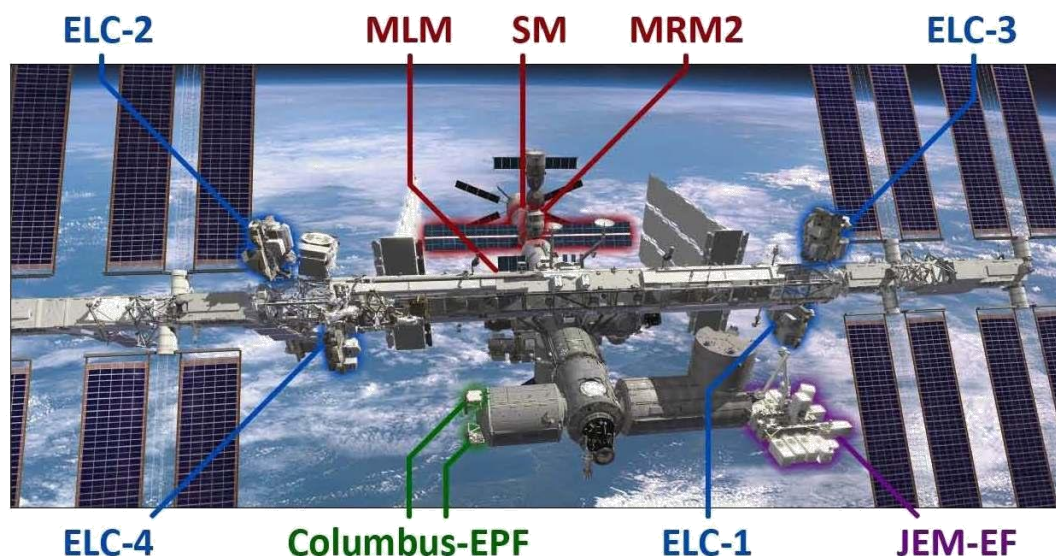
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- Intra International Space Station (ISS) payloads sites have limited bus throughput ( $\sim 10$  Mb/s) restricting communicating large quantities of science data



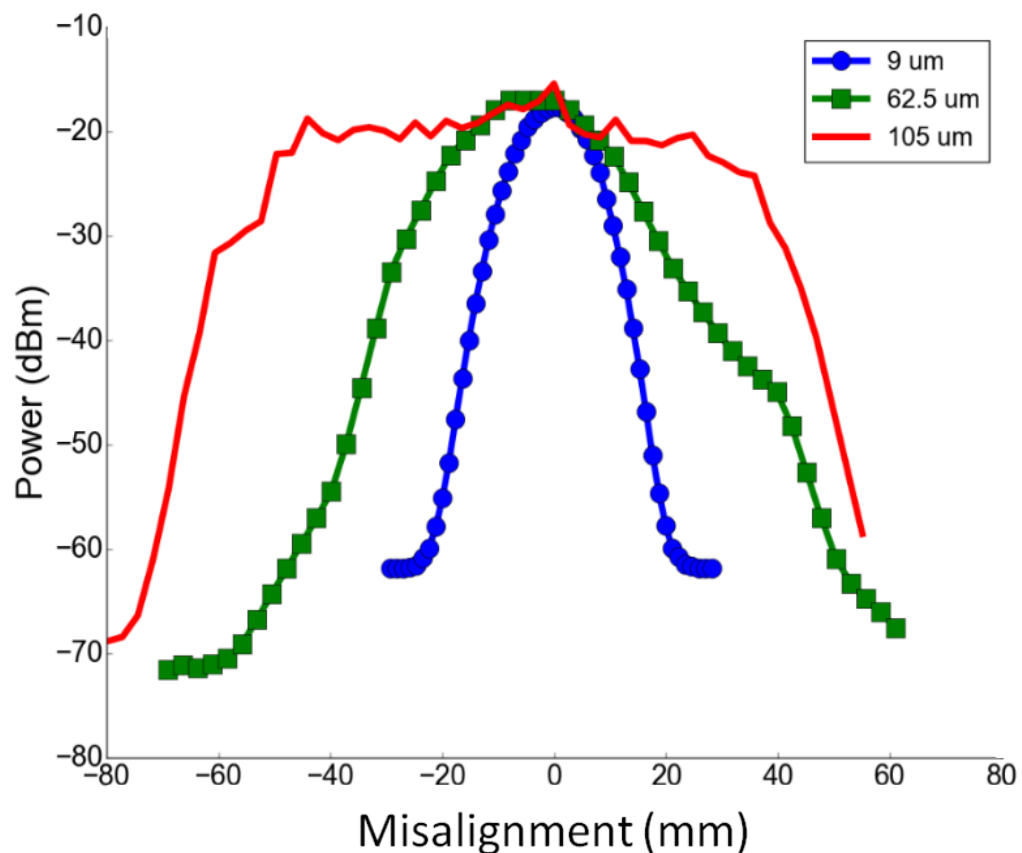
- Free Space Optical Links can implement high rate data transfer with little change in the current infrastructure
- Passive Solutions are being investigated to minimize Size, Weight, and Power (SWaP)
- ELC motion relative to the main cabin is predicted cause up to  $\pm 5$  cm lateral misalignment



# Background: Lateral Misalignment Tolerance

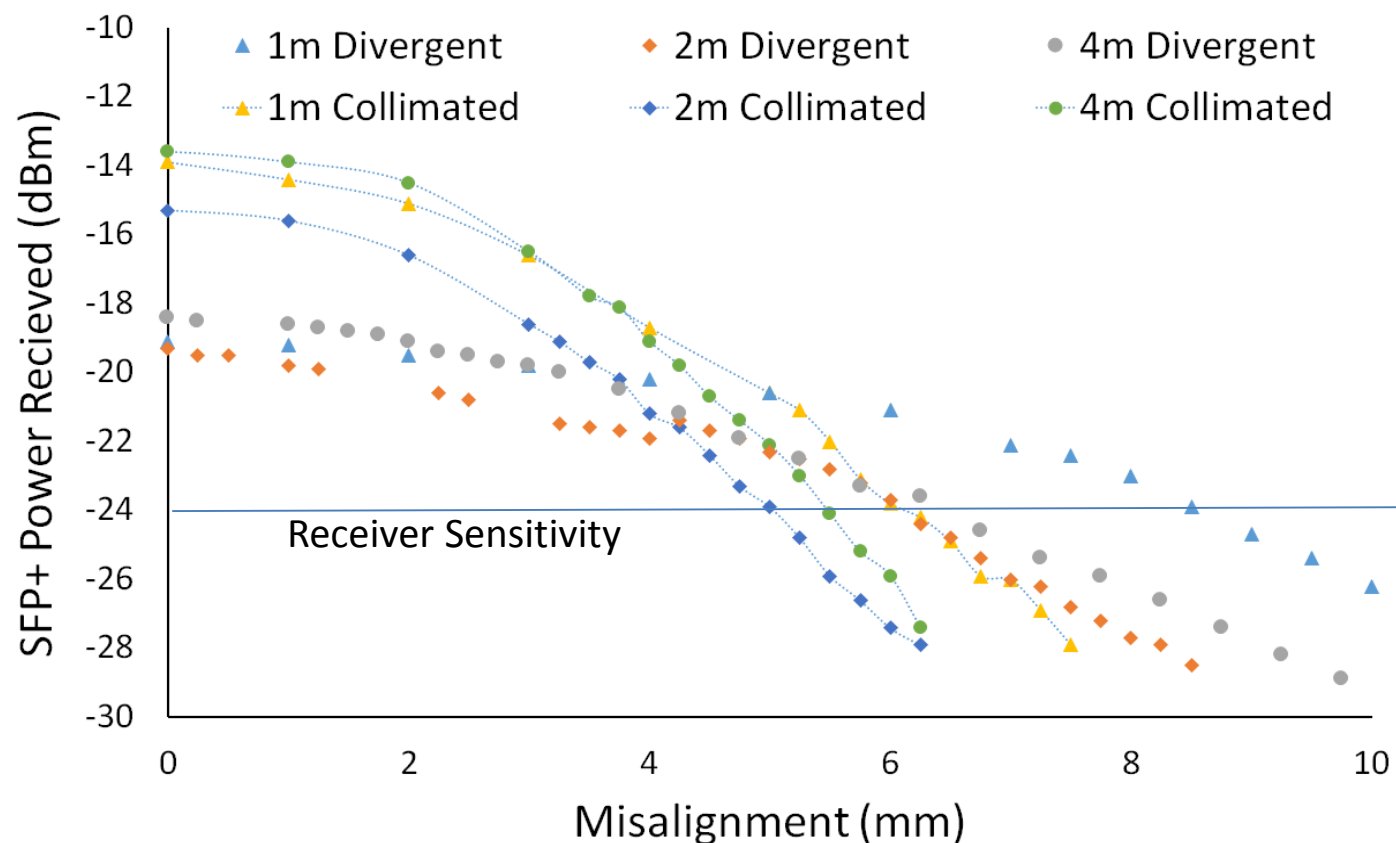


**Past Work:** A 105  $\mu\text{m}$  core multi-mode fiber (MMF) provides increased receiver field of view

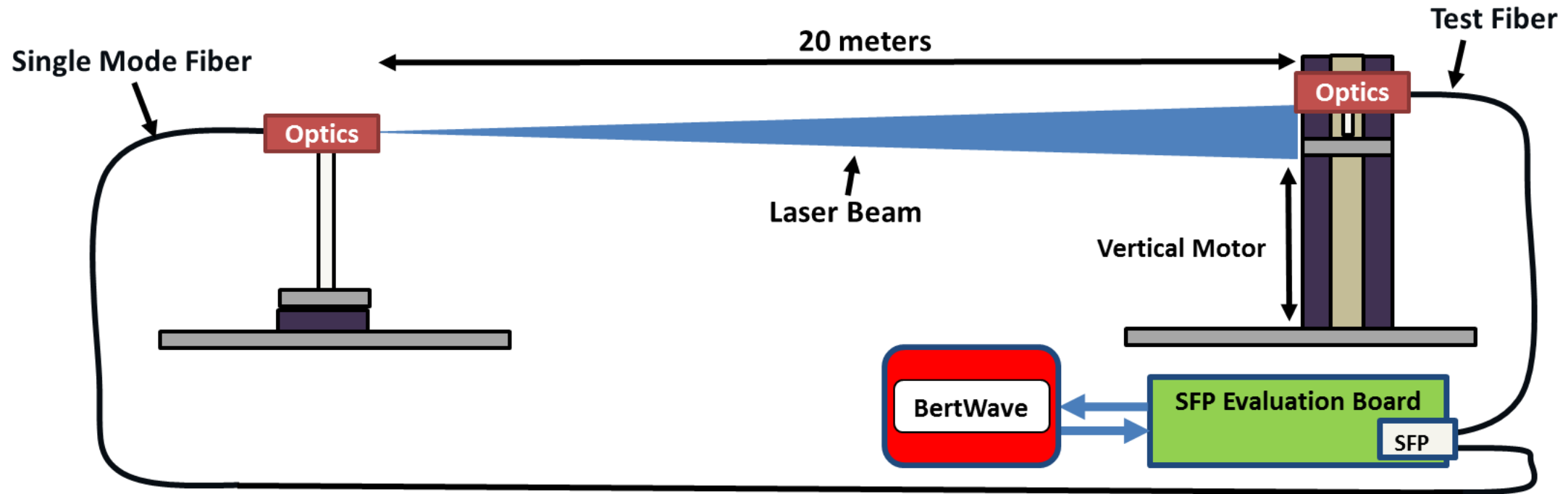


\*Data taken with fiber coupled power meter

**Present Work:** Use a small form factor pluggable (SFP) optical transceiver with a 105  $\mu\text{m}$  core fiber at the receiver



\*Data taken with reported SFP+ power



**Automatic control of beam divergence using linear positioner, lateral misalignment using vertical motor, sfp+ power reading using I2C interface, BertWave measurement using TCP/IP connection**

Receive Optical Assembly installed with automatic alignment devices

SFP+ Evaluation PCB with SFP+ installed

BERT will take measurements until a predefined confidence level is met

$$C_L = 1 - e^{-N_{bits} * BER}$$

$$C_{LE} = 1 - \left( e^{-N_{bits} * BER} * \frac{1}{N_{error}!} * (BER * N_{bits}^{N_{error}}) \right)$$

Control PC to interface with all components

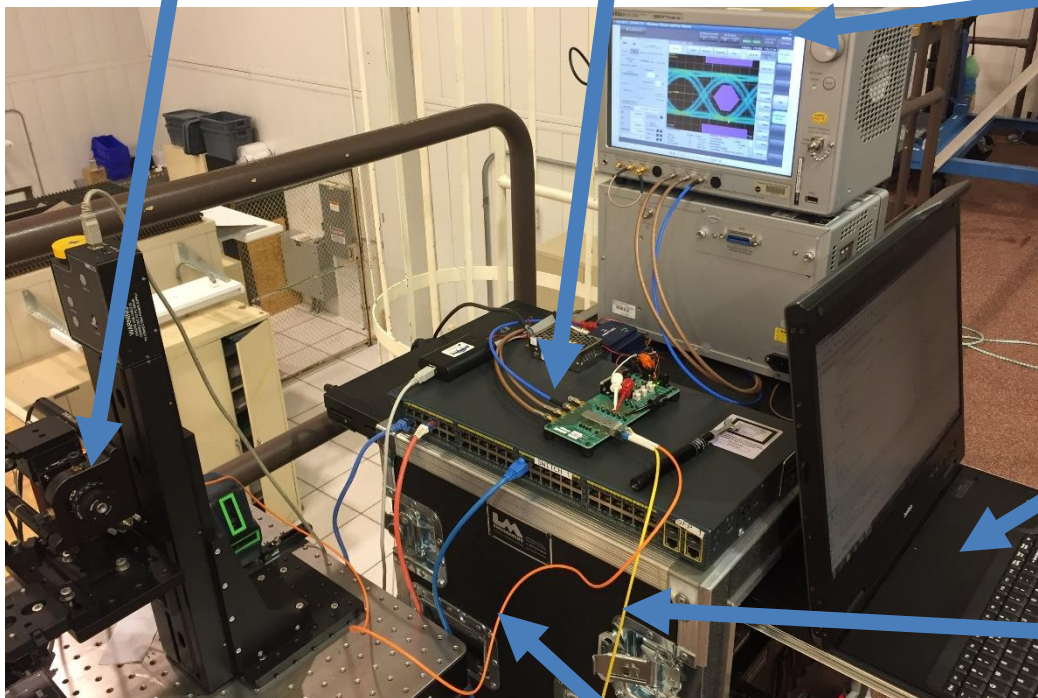
Transmit Fiber (SMF)

Receive Fiber (MMF/DUT)

Receive Optical Assembly



Transmit Optical Assembly





# Modal Dispersion: Theoretical Data Capacity



Pulse dispersion

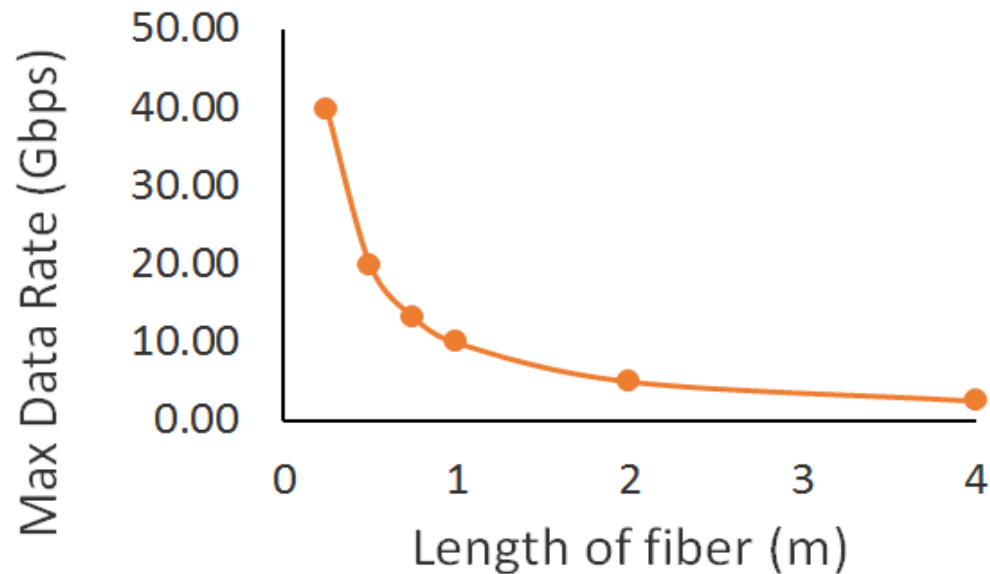
$$\tau_i \approx \frac{L}{2n_1c} (NA)^2$$

Material dispersion

$$\tau_m = D_m \times L \times \Delta\lambda$$

Max Bit Rate

$$B_{max} = \frac{0.7}{\sqrt{\tau_i^2 + \tau_m^2}}$$



105  $\mu\text{m}$  pure silica core with 125  $\mu\text{m}$  fluorine-doped silica cladding:

$$n_1 = 1.4439$$

$$NA = 0.22$$

$$D_m = 21.5187 \text{ ps/nm-km}$$

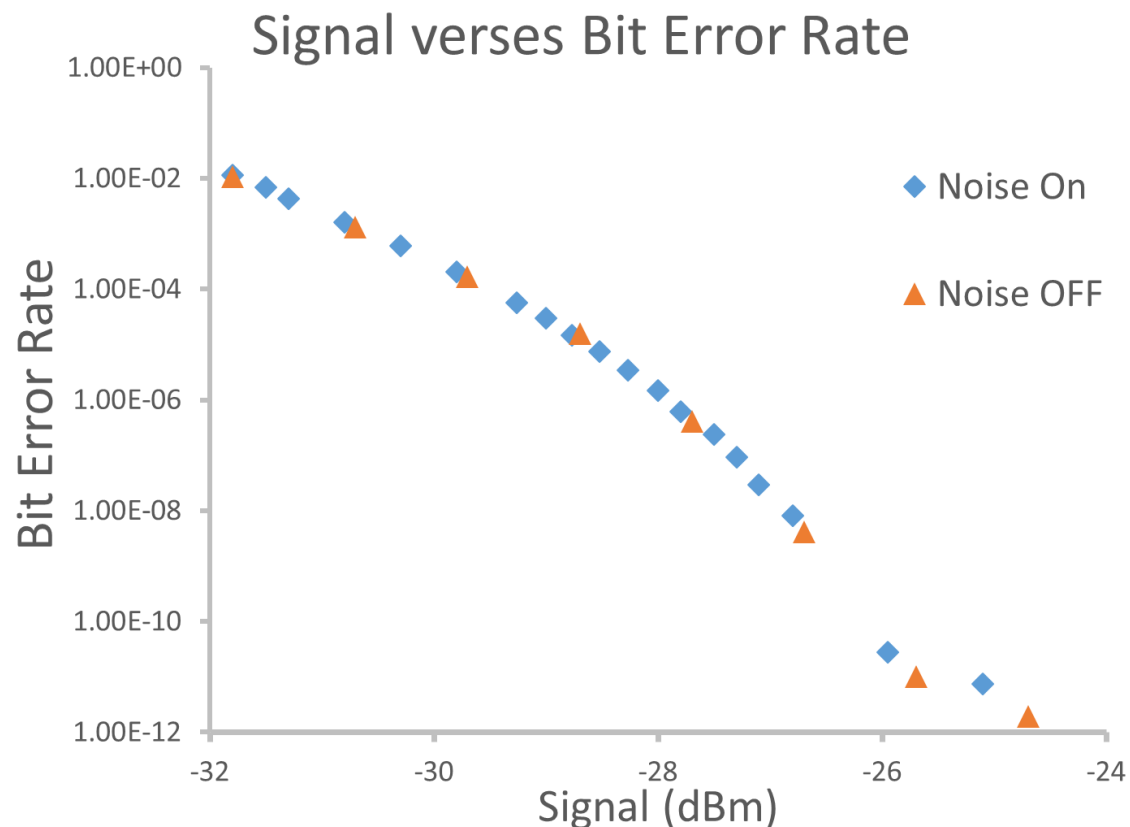
$$\Delta\lambda = 2 \text{ nm}$$

$$c = 3e8 \text{ m/s}$$

**Test fibers chosen for this experiment are 1 meter, 2 meters and 4 meters to show modal dispersion at 10 Gpbs**



# Signal to Noise Ratio: Test

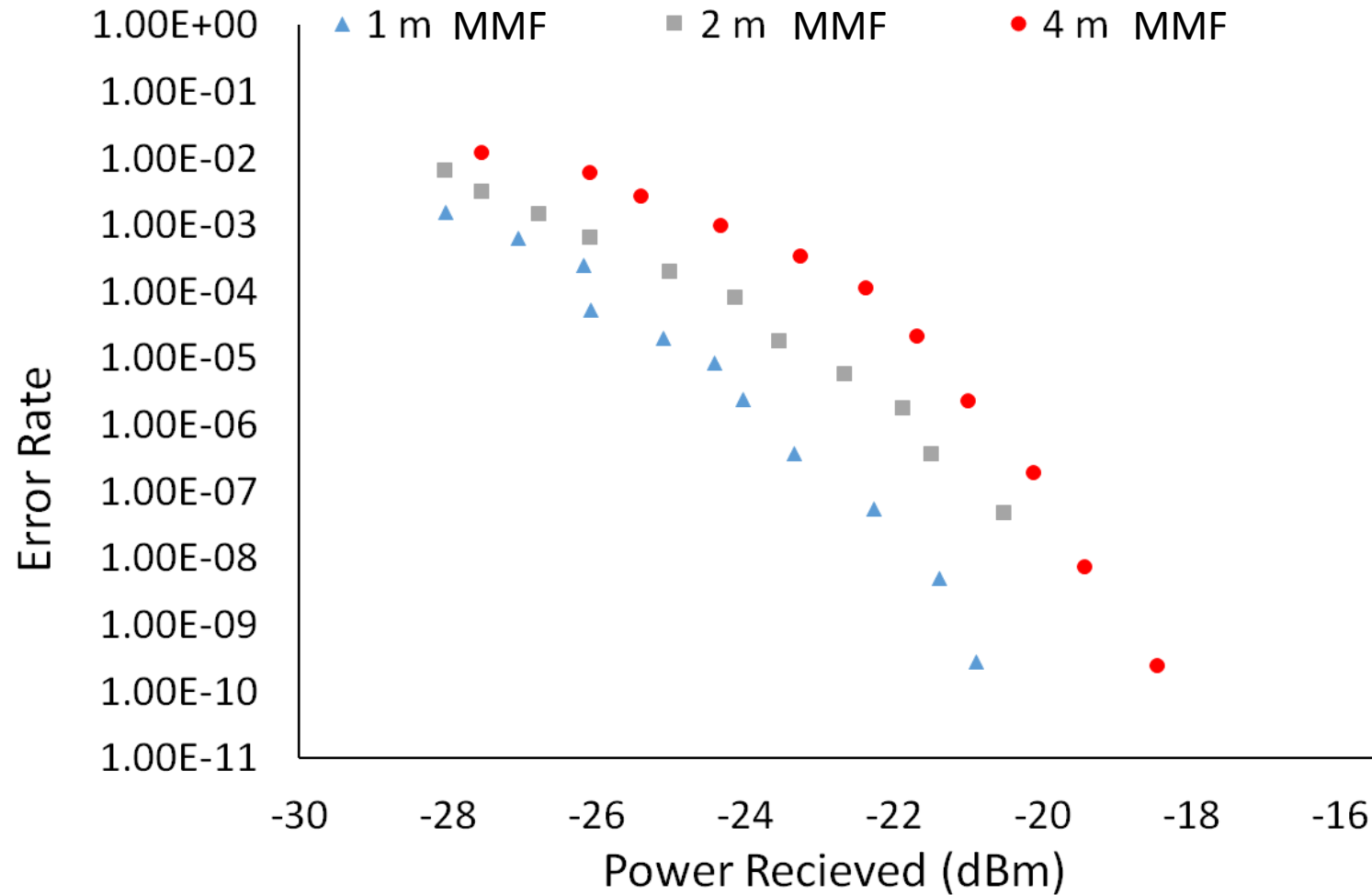


Noise was added to the optical signal using a tungsten light and fiber combiner at the receiver. This increased the optical noise from -78.1 dBm/nm to -61.8 dBm/nm.

**Electrical noise has a greater effect on Bit Error Rate than ambient optical noise for our test system. By adjusting the signal power the noise floor remains constant thus changing the SNR**



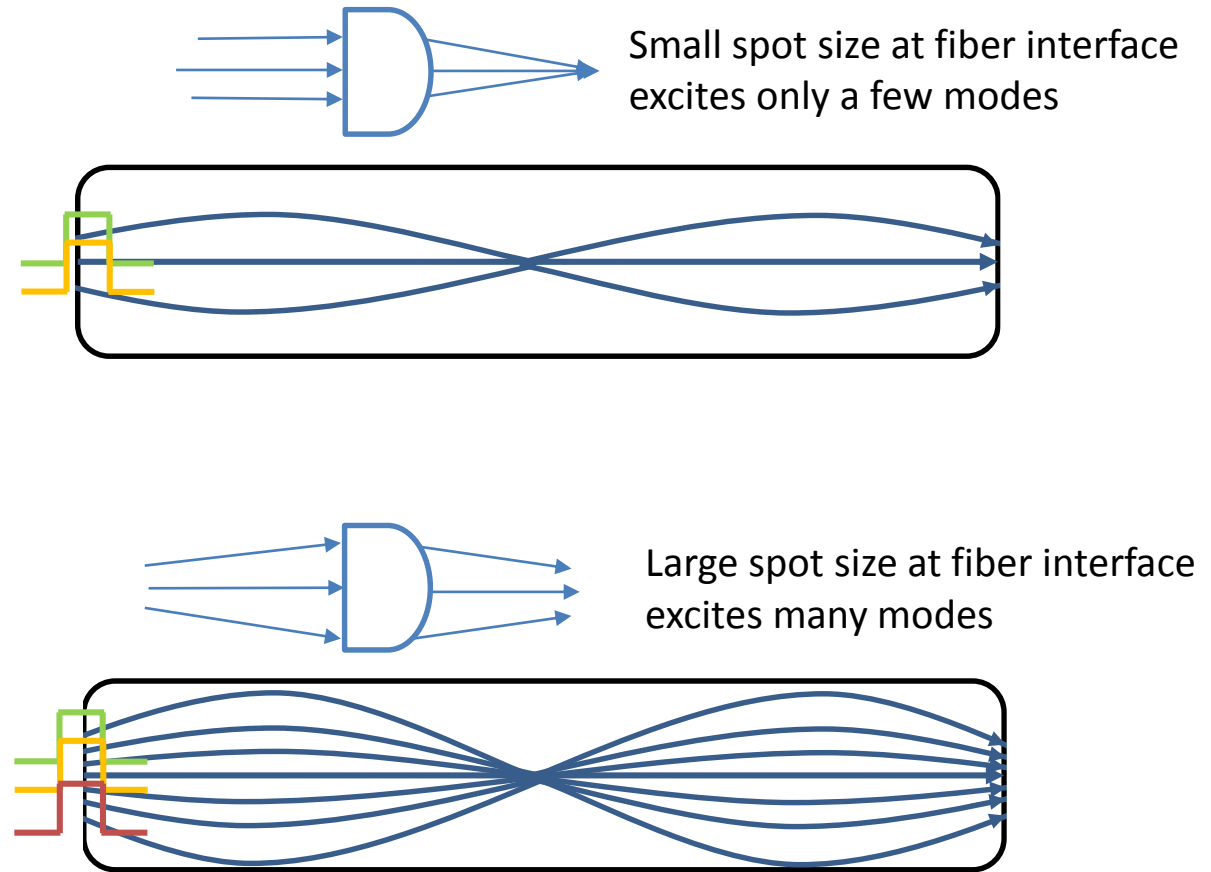
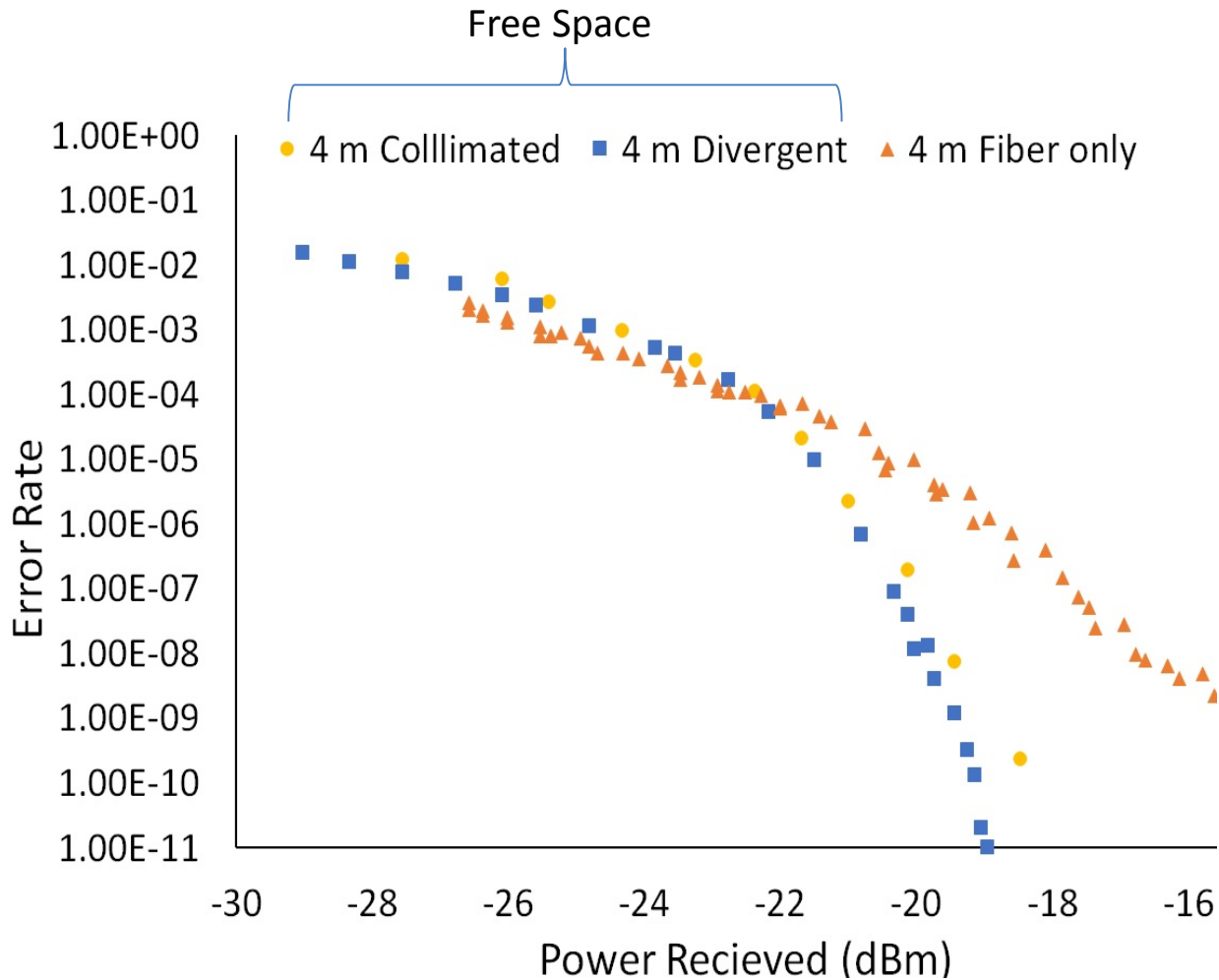
# BER vs Power for various MMF cable lengths



**BER performance decreases as cable length increases.**



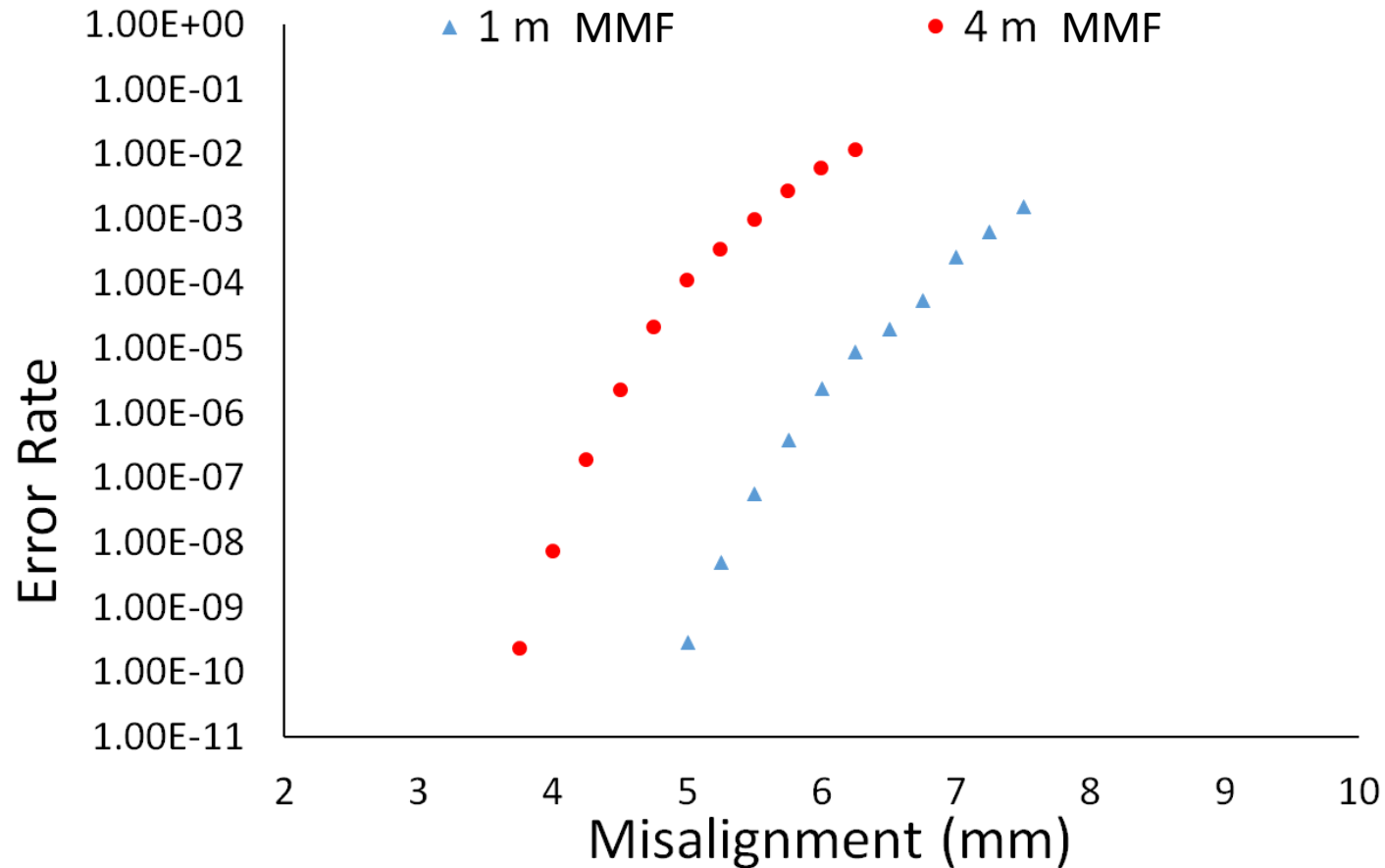
# BER vs Power for various Launch Conditions



**BER performance increases for high SNR points as the number of excited modes is increased due to differential mode delay**



# BER vs Misalignment for various MMF cable lengths



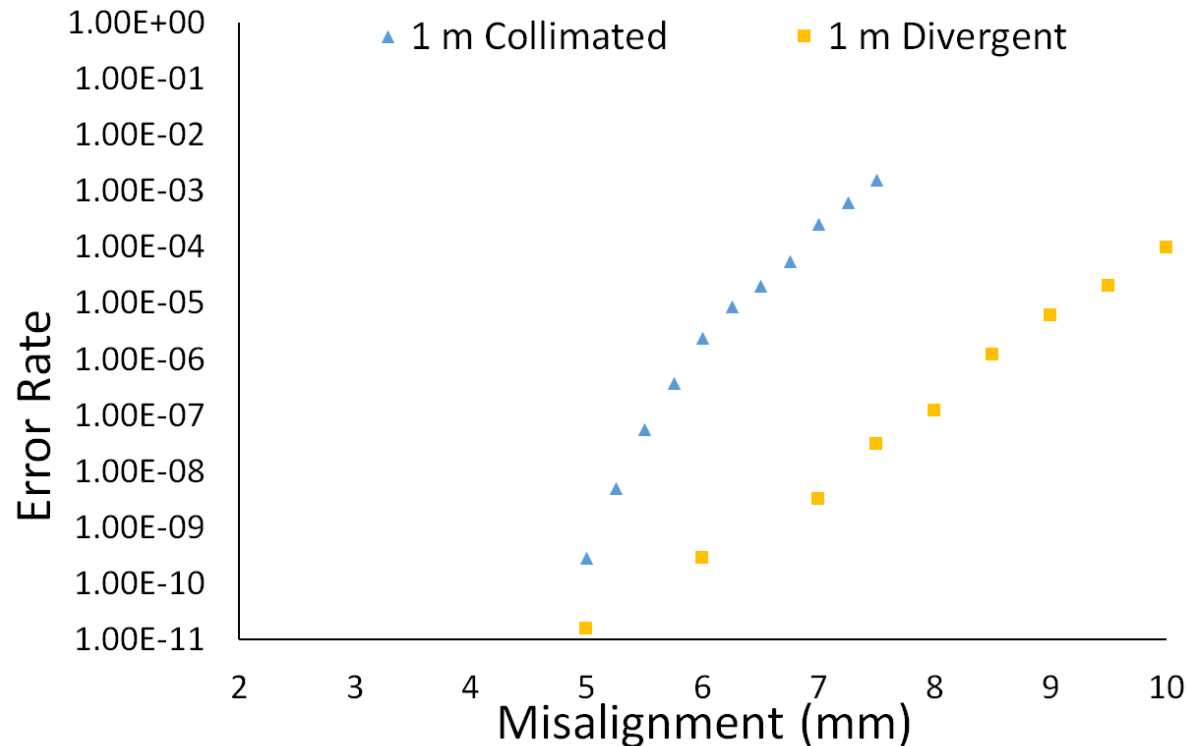
**For a given error rate the shorter cable achieves greater misalignment tolerance**



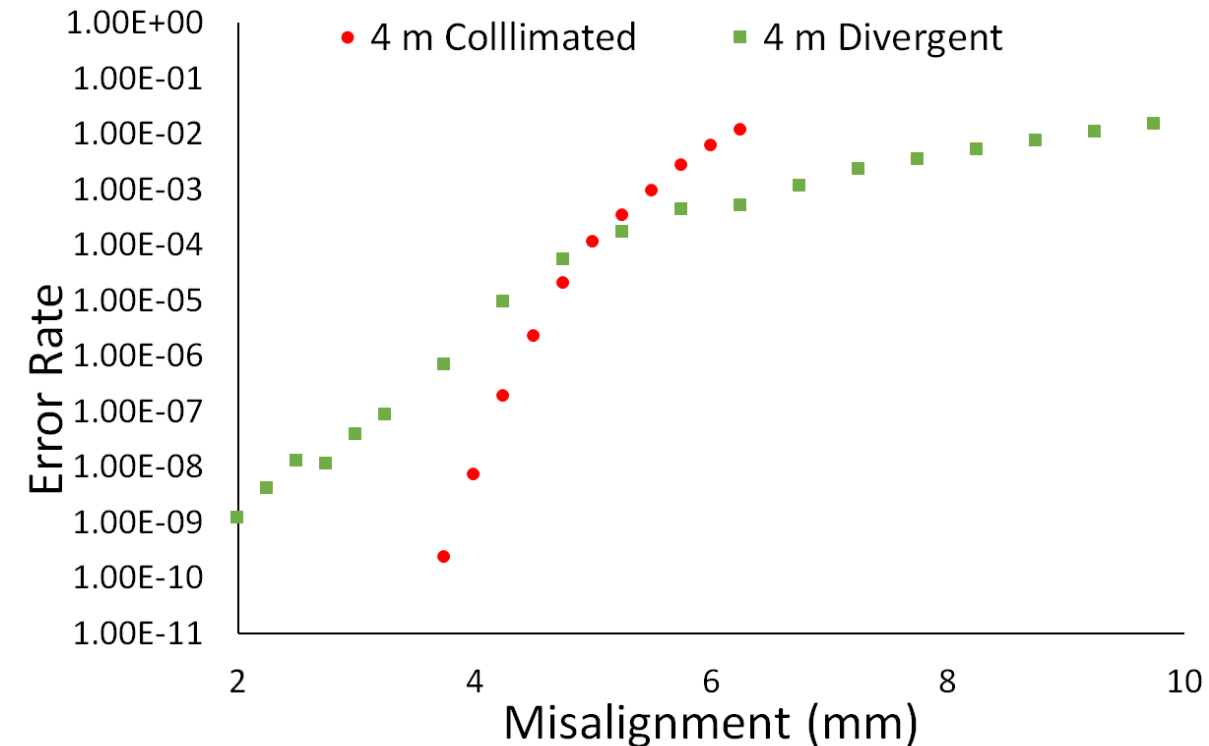
# BER vs Misalignment for various Launch Conditions



BER vs Misalignment for different launch conditions using a 1 m MMF cable



BER vs Misalignment for different launch conditions using a 4 m MMF cable



**For a given length of cable length there is a error rate at which a divergent beam becomes better then the collimated beam, this crossing point tell us that there is an optimal divergence for a given error rate.**

## Summary

- The automated FSO BERT system was presented
- Results were presented on BER performance of a 20 meter FSO using various lengths of a 105  $\mu\text{m}$  MMF to which differential mode delay was observed
- The 105  $\mu\text{m}$  MMF and optimal launch condition show potential for an Intra ISS FSO system

## Future Work

- Investigate efficient power coupling between the 105  $\mu\text{m}$  MMF and SMF ROSA (receive optical sub assembly)
- Further investigate modal dispersion using an eye diagram and its quantifiable metrics (Jitter and Amplitude)
- Investigate launch condition and mode excitation of the MMF given a divergent beam collected in free space

